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The Spacewatch Telescope on Kitt Peak is used for the ongoing program of surveillance for small moving objects in the solar system. At least 20,000 main-belt asteroids are found per year; their positions are e-mailed to others. For the near-Earth objects, the discovery rate now is about 30 per year. These are followed up as much as possible in order to obtain the best possible orbits. Spacewatch participates in the observing campaign for P/Comet-Levy 9. Dr Robert Jedicke joined us as Research Associate. Public interest in the Spacewatch program continues; nearly every observing run a reporter or television crew joins us for an evening. The origin of the 10-m objects, small objects near the Earth called "Arjunas," is being studied as is the chaotic behavior of "Centaurs" in the outer parts of the solar system. The construction of the 1.8-m Spacewatch Telescope proceeds, without impact on the research and observations with the 0.9-m. The 1.8-m is being built in the Instrument Development Shop of the University of Arizona. Because of limited funding, its design was changed into an alt-az reflector with folded prime focus.

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PROGRESS REPORT

AFOSR F49620-92-J-0051 DEF

December 7, 1993

Abstract

The Spacewatch Telescope on Kitt Peak is used for the ongoing program of surveillance for small moving objects in the solar system. At least 20,000 main-belt asteroids are found per year; their positions are e-mailed to others. For the near-Earth objects, the discovery rate now is about 30 per year. These are followed up as much as possible in order to obtain the best possible orbits. Spacewatch participates in the observing campaign for P/Comet-Levy 9. Dr. Robert Jedicke joined us as Research Associate. Public interest in the Spacewatch program continues; nearly every observing run a reporter or television crew joins us for an evening. The origin of the 10-m objects, small objects near the Earth called "Arjunas," is being studied as is the chaotic behavior of "Centaurs" in the outer parts of the solar system. The construction of the 1.8-m Spacewatch Telescope proceeds, without impact on the research and observations with the 0.9-m. The 1.8-m is being built in the Instrument Development Shop of the University of Arizona. Because of limited funding, its design was changed into an alt-az reflector with folded prime focus.

A slow observing year of 1992 ended with the promise of things to come when a Very Fast Moving Object (VFMO) was discovered on 27 December 1992 which was given the provisional designation of 1992 YD3. This object was estimated to be between 20 and 40 meters in diameter. It is a member of the class of Small Earth Approachers we have called "Arjunas" as defined by Rabinowitz *et al.* (1993).

The 1993 observing year has yielded 26 new NEAs between and including the January and November observing runs. There were 9 objects smaller than 100 meters diameter, 11 between 100 meters and 1 kilometer in diameter, and 6 larger than 1 kilometer in our 1993 tally to date. Particularly noteworthy objects include the rediscovery of 1991 CB1 (=1993 BV3), which is a Spacewatch discovery from 1991 February, serendipitously discovered in late January and identified by Scotti as 1991 CB1.

(5693), 1993 EA, discovered in March, was identified as 1984 AJ by Marsden at the Minor Planet Center, an object observed on just one night at Palomar in 1984 and linked furthermore with images of the object found in 1986 at Siding Spring and 1989 at Palomar and Siding Spring. The resulting long arc allowed this object to be numbered quickly.

On May 21, Gehrels discovered another VFMO whose angular rate of motion decreased from 29 degrees per day when first identified to just 12 degrees per day at the end of the night. This object, designated 1993 KA2 is the faintest and closest NEA yet discovered, superseding 1991 BA (discovered by Spacewatch on 1991 January 18) in both faintness and closest approach distance. The change in angular rate during the night can be understood readily by visualizing an airplane overhead: it has high angular rate of motion, which decreases as the plane moves away in the distance. 1993 KA2 passed the Earth at 150,000 km from the center of the Earth about 5 hours before it was discovered.

1993 PB was the largest NEA discovered by Spacewatch in 1993 having an estimated diameter of between 1.6 and 3.2 kilometers. 1993 PB also possesses the highest inclination of the 1993 discoveries at 41 degrees. Two new Aten-type asteroids with orbital periods less than 1 year were discovered in 1993, the first being 1993 DA in February and 1993 VD in November.

Other objects of interest found by Spacewatch include the 3rd identified "Centaur" type asteroid, 1993 HA2, discovered by Rabinowitz in April. "Centaur" asteroids orbit in the outer solar system and may be a link between the Oort cloud and the Jupiter Family of short-period comets. Of the 3 known thus far, (2060) Chiron has recently exhibited cometary activity. (5145) Pholus (discovered by Spacewatch in 1992 January) and 1993 HA2 have shown no signs of cometary activity, but instead appear to be the reddest objects known in the solar system, perhaps showing evidence for a cosmic-ray-induced organic crust which may be present on new comets which have yet to visit the inner solar system.

In the evening of 25 March 1993, Scotti received a phone call from Gene Shoemaker and David Levy at Palomar reporting their discovery of an unusual looking comet. Spacewatch was used that night to confirm the object and to identify a train of more than 8 nuclei (later counts by

other observers have found more than 20 individual nuclei) as well as trails of dust and tails extending from the nuclear train. Analysis of the subsequent motion of the comet by Marsden and Nakano found that the object was in orbit around Jupiter, had passed within the Roche limit of Jupiter in July of 1992, and will impact on Jupiter in July of 1994. Using the length of the train of nuclei, Scotti and Melosh (1993) were able to estimate the size of the progenitor of the comet as being just 2 kilometers by assuming the comet suffered tidal breakup at the time of perijove in 1992 July. Others disagree, and find the diameter to be as large as 10 km.

On 24 October 1993, Scotti discovered a 17th magnitude comet which he tentatively identified as long lost comet P/Spitaler, last seen during its discovery apparition in 1890. Later observations confirmed the identification.

In addition to these interesting discoveries, automated astrometry using the Hubble Space Telescope Guide Star Catalog for approximately 20,000 incidental asteroid detections were reported to the Minor Planet Center where G. V. Williams was able to identify approximately 20% as being either previously known asteroids or as being observed more than once with Spacewatch. These identifications have made substantial contributions to the improvement of orbits for the many main-belt asteroids that have been detected with Spacewatch.

Dr. Robert Jedicke joined us in September 1993 as a Research Associate, taking the place of Rabinowitz who continues to observe and collaborate with us from the Carnegie Institution in Washington, D.C. Jedicke came from the Fermi Laboratory; with his thorough training in physics, mathematics and computer usage, he is catching on quickly to the Spacewatch programs.

Presentations at meetings were made and papers were written on several aspects of Spacewatch research. The origin of the Arjunas is being investigated in several papers by others as well as by us. These objects could be secondary debris from the Moon, Mars, or from secondary collisions of the near-Earth objects. First, the collisions in the asteroid belt occur, and Jupiter brings the fragments to the inner part of the solar system. The magnitude-frequency relation follows the one expected for fragmentation, even in the case of a hammer hitting a rock and breaking it into small pieces. Toward smaller sizes there is a rapid increase in the number of objects, a factor of 2.5 per astronomical magnitude. At about 10 m size, the collision probabilities among themselves are sufficient to get secondary collisions in less than 10^8 years, appreciably less than the lifetime of the solar system. The chaotic behavior of the Centaurs is also being pursued. Major review chapters have been written on these subjects in the book, *Hazards Due to Comets and Asteroids*, that is being assembled with Gehrels as Editor as the 25th book in the Space Science Series of the University of Arizona Press.

The public interest in the Spacewatch program continues. Nearly every month a television crew or science writer come to Kitt Peak for an evening of interviews or filming for publication or televising. Reports have appeared in American, Australian, Italian, French, Dutch and Canadian journals and networks.

Both the primary and secondary mirrors of the 0.9-m telescope were realuminized by McMillan and his crew in September. The net gain in light collection is at least 0.3 mag. The platform elevator break had to be rebuilt when an asbestos lining disintegrated. Asbestos material is no longer permitted; the new lining is made of graphite-epoxy composite.

Delivery of mirror No. 5 from the Multi-Mirror Telescope (MMT) and its cell occurred during this report period. The mirror is the one with the best overall figure for imagery, and is aluminized and protected by Opti-Coat until we are ready to use it. The cell is mature, functional hardware, mechanically tuned to this mirror, and used successfully in the MMT in the past. Some spare handling hardware also was donated by the MMT Observatory, whose personnel remain available to advise us on the handling and use of the mirror.

The zenith-pointing test tower in the hangar at Ryan Field is structurally complete. It will be used to develop the focal plane instrumentation with the 1.8-m mirror, while the actual 1.8-m telescope is being constructed in the Instrument Development Shop on the campus.

A flat secondary mirror was added to the optical configuration to shorten the telescope tube. The flat will redirect the converging beam back along the optical axis so the instrument package will be suspended inside the tube, just forward of the elevation axis. The advantages of the folded design are a smaller dome, incurring essential cost savings, a smaller moment of inertia for the telescope, and considerably less sensitivity of the mechanical design to the weight of the science payload. The optical configuration, including the corrector, has now been "frozen" so the mechanical design effort can proceed.

A site adjacent to the 0.9-m Spacewatch Telescope on Kitt Peak has been tentatively designated by us and approved by the Directors of LPL and Steward Observatory. We are comparing this site to the one on the west ridge of Kitt Peak previously assigned to Spacewatch by the Director of the Kitt Peak National Observatory.

Our consulting mechanical engineer, Mr. L. D. Barr, is feeding conceptual assembly drawings to a full-time drafter, who makes individual part drawings using AutoCad software. All the resulting drawings are in machine-readable form as well as in hard copy. The drafter works in an office at the University Instrument Shop, where welders and machinists are making the parts. This arrangement is working quite smoothly. A large, precision steel component of the telescope, the azimuth base disk, was welded, annealed, and machine-faced in October. No hitches developed in the fabrication of this large disk, which is more than 6 feet in diameter and was expected to be one of the more difficult components to make.

The pedestals that support the elevation bearings above the azimuth base disk are presently being welded. Details of the azimuth drive motors' mechanical and electronic configuration are being worked out in consultation with potential vendors.

In conclusion, we thank AFOSR for this year of support for Spacewatch activities, which benefit not only the sky surveillance for moving objects, but also McMillan's radial-velocity search for planets of other stars which uses the telescope during the bright time, centered on full moon, of each month.

PUBLICATIONS

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Rabinowitz, D.L., Detection of Earth-approaching Asteroids in Near Real Time, Astronomical Journal, Vol 101, pp 1518-1559

Rabinowitz, D.L., The Size Distribution of the Earth-Approaching Asteroids, Astrophysical Journal, Vol 407, pp 412-427, April 10, 1993

Rabinowitz, D.L., Gehrels, T., Scotti, J.V., McMillan, R.S., Perry, M.L., Wisniewski, W., Larson, S.M., Howell, E.S. and Mueller, B.E.A., Evidence for a Near-Earth Asteroid Belt, Nature, Vol. 363, p 704, 1993

Scotti, J.V. and Melosh, H.J. Tidal Breakup and Dispersion of P/Shoemaker-Levy 9: Estimate of Progenitor Size, Nature, Vol 365, pp 733-735, 1993

PROFESSIONAL HONORS

Gehrels

American Astronomical Society
International Astronomical Union

V.A. Sarabhai Professor and Honorary Fellow, Physical Research Laboratory, Ahmedabad, India, 1978-present

Vainu Bappu Memorial Lecture, "Beauty and Danger of Comets and Asteroids," Asian Pacific Regional Meeting of the International Astronomical Union, India, August 1993

McMillan

American Astronomical Society
International Astronomical Union
Society of Photo-optical Instrument Engineers

Scotti

American Astronomical Society
Association of Lunar and Planetary Observers

Invited Review Talk: "Computer-aided Near-Earth Object Detection--A Spacewatch Perspective," Asteroids, Comets, Meteors 1993, International Astronomical Union Symposium 160, Belgirate (Novara), Italy, June 1993.

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American Astronomical Society

Rabinowitz

American Astronomical Society
Sigma Xi, University of Chicago Chapter
NASA Predoctoral Fellowship, University of Chicago, 1985-87
Lewis P. Meyer Scholarship, Yale University, 1982-83

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Guest Scientist, Fermi National Accelerator Laboratory, Batavia, IL, 1991-1992